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## G Stress on A-10 Pilots During JAWS II Exercises

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G<sub>z</sub> loads in A-10 aircraft were recorded on nine sorties during JAWS II exercises, and the pilots completed questionnaires on the effects of G stress in the A-10. Analysis of the recordings provided, among other statistics, the following means: maneuvering time, 28 min; peak +G<sub>z</sub> load, +6.2; peak -G<sub>z</sub> load, -0.1; G-time integral above 4 G, 83 G-s; G onsets  $\geq 6$  G/s, 13. The questionnaires and follow-up interviews generated little evidence of G intolerance; the pilots did report significant task saturation, however. To compare the physiologic effects of G stress in the A-10 with those of G stress in the F-4, eight volunteer subjects were exposed to simulated A-10 and F-4 missions on the USAFSAM centrifuge. Although the two G-stress profiles were equally difficult and fatiguing, the subjects experienced less visual loss and had lower maximum heart rates during the A-10 profile.

AT THE REQUEST OF the USAF Tactical Air Command, representatives of the Crew Technology Division, USAF School of Aerospace Medicine, observed the operation of the A-10 aircraft (Fig. 1) during Phase II of the Joint Attack Weapons System (JAWS) evaluation, held at Fort Hunter-Liggett, CA, 7-18 Nov. 1977. This exercise involved the use of A-10s, attack helicopters, and ground forces in various combinations against simulated enemy forces employing tanks, aircraft, and sophisticated air defense weapon systems. The battle conditions were quite realistic, with daily reports of each side's electronically scored kills serving to enhance the motivation of the participants. Our mission was to collect data on pilot stress and fatigue during and after the A-10 sorties, analyze and interpret the data in terms of physiologic cost per sortie, and recommend revising the crew duty day or manning ratio if stress and fatigue threatened to compromise the A-10 pilots' performance or safety. Of particular interest to us was the G stress experienced by the A-10 pilots. We had anecdotal evi-

dence that the jinking maneuvers employed by A-10 pilots to deprive the enemy of a readily trackable target resulted in a nearly constant exposure to moderate levels of G stress, with frequent excursions to relatively high G levels. If substantial fatigue were to be documented as characteristic of A-10 operations, we wanted to know the contribution of G stress to that fatigue.

### METHODS

Continuous time records of +G<sub>z</sub> load on the aircraft were obtained on eight sorties with an Inflight Phys-



Fig. 1. An A-10 aircraft maneuvering during JAWS II exercises. Note low altitude and high angle of bank, typical of A-10 operations. (Photo courtesy of Fairchild Republic).

The voluntary informed consent of the experimental subjects used in this research was obtained in accordance with AFR 169-3.

iological Data Acquisition System (IFPDAS) module (6) placed in the ladder-storage compartment just outside the cockpit, and on one sortie with it placed in a special vest worn by the pilot. In the latter case, ECG and respiratory flow data were also collected. Calibration of the IFPDAS G-recording system was accomplished before and after each mission by setting the accelerometer upright, on its side, and upside down, thus generating calibration signals of +1.00 G, 0.00 G, and -1.00 G, respectively. The IFPDAS was also exposed on the USAFSAM centrifuge to known G loads in the +1.00 to +8.00-G range. The system exhibited static measurement errors from less than 0.05 G at  $\pm 1.00$  G to less than 0.20 G at +8.00 G. Visual inspection of responses to step inputs ascertained that the dynamic response of the system was adequate to measure changes in G loading at G-onset rates of up to 16 G/s.

Questionnaire A was completed by all eight participating pilots prior to the beginning of the JAWS II exercises; this questionnaire requested age, height, weight, flying experience, exercise habits, estimated G tolerance, and pilots' comments on G stress in the A10. Questionnaire B was given to the pilots after each sortie; this one requested information on the physical and mental effort exerted, and the stress and fatigue experienced, during the preceding flight. Nineteen of these post-mission questionnaires were completed and analyzed.

Tape-recorded interviews with each of the pilots were also obtained. The interviews gave the pilots a chance to expand upon comments made by them on the questionnaires, and gave us the opportunity to ask questions about things not anticipated prior to beginning the study.

Finally, eight experienced centrifuge riders rode the USAFSAM human centrifuge on a G profile designed to reproduce the G stress recorded in the A-10, and compared the stress of that profile with the stress of a G profile representative of an aerial combat engagement

in an F-4 aircraft. Subjective fatigue, difficulty, and visual loss associated with each profile, as well as heart rate and cardiac dysrhythmias observed during each run, were used to assess the relative tolerability of the G forces recorded in the A-10.

## RESULTS

*Inflight recordings:* A summary of the G<sub>r</sub>-load data obtained from the IFPDAS is presented in Table I. Although each mission lasted approximately 1.5 h, the time spent in or near the battle zone was 37 min on the average; of that, about 28 min (range: 19-39 min) was spent in hard maneuvering. Fig. 2 is an example of the G stress recorded during the maneuvering portion of an A-10 mission. The mean peak G attained in the nine sorties was +6.2 G, with +6.7 G being the highest value recorded. The mean total time spent above 6.0 G was 2.9 s, and the mean number of excursions above 6.0 G was 3.7; so the mean time spent above 6.0 G per excursion calculates to be 0.7 s. Similarly, the mean time spent above 5.0 G was 29.7 s, and the mean number of excursions above that level was 20.8; so only 1.4 s was spent on each excursion above 5.0 G, on the average. Considerably more time was spent above 4.0 G—a mean of 156.8 s, and a range of 37-305 s. A mean of 63.1 excursions above the 4.0-G level was recorded; each excursion above 4.0 G thus lasted an average of 2.5 s. Although there was considerable maneuvering in the range between 0 and +1.0 G, an average of only 6.8 peaks below 0 G, totaling 4.8 s (0.7 s/peak), was recorded. No peaks below -0.5 G were generated during the sorties monitored. Of interest was the fact that one pilot, the commander of the A-10 contingent, appeared to have used "outside" maneuvers much more frequently than the others, as he spent a per-flight average of 11.2 s below 0 G on three flights, while the other pilots managed to register a per-flight average of only 1.6 s below

TABLE I. SUMMARY OF G-EXPOSURE DATA  
FROM NINE A-10 SORTIES DURING JAWS II EXERCISES.

Parameter	Maximum	Minimum	Mean	S.D.
Total maneuvering time (min)	51.6	26.8	37.1	8.1
Maneuvering time minus rest periods	37.8	19.2	27.9	5.0
Peak +G, load	6.7	5.2	6.23	0.55
Peak -G, load	-0.4	+0.4	-0.09	0.23
Number of peaks:				
$\geq 6$ G	8	0	3.7	2.8
$\geq 5$ G	37	2	20.8	13.1
$\geq 4$ G	123	18	63.1	30.8
$\leq 0$ G	24	0	6.8	7.9
Time spent (s):				
above 6 G	7	0	2.9	2.3
above 5 G	50	1	29.7	16.7
above 4 G	305	37	156.8	79.6
below 0 G	13	0	4.8	5.1
G-time integrals (G·s):				
above 4 G	148	12	85.1	47.5
above 1 G	2205	1080	1745.0	365.0
below 0 G	5	0	1.1	1.7
Number of G onsets:				
$\geq 4$ , < 6 G/s	29	2	18.6	8.4
$\geq 6$ , < 8 G/s	11	1	6.9	3.3
$\geq 8$ G/s	15	0	5.9	4.5

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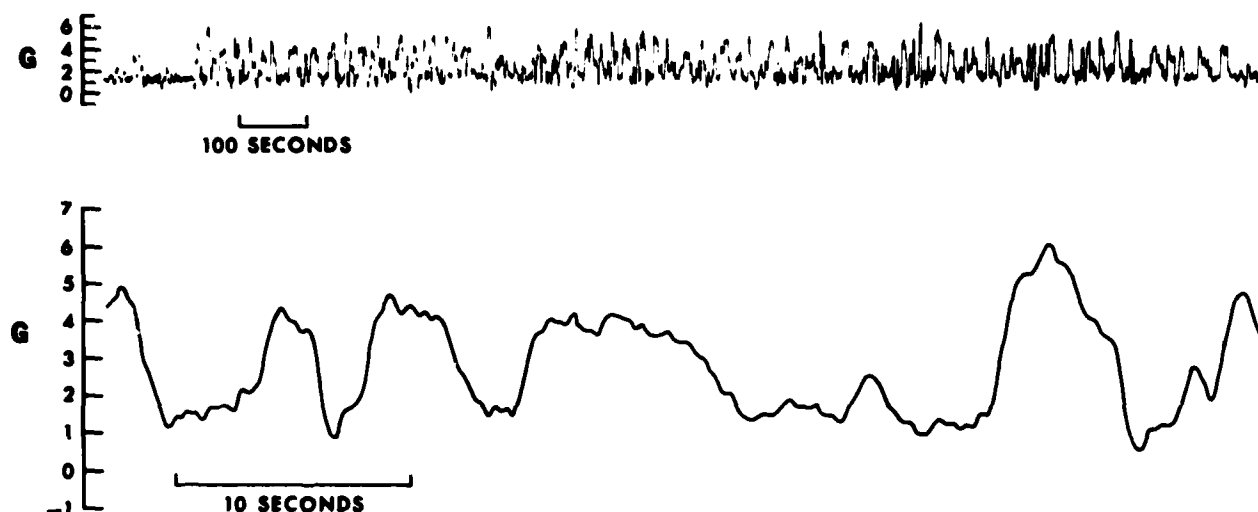


Fig. 2. Typical A-10 G-load profiles recorded during JAWS II exercises. Upper: 30 min of simulated combat. Lower: 45 s from upper record.

0 G for the remaining six flights.

Four parameters we find useful for evaluating the stressfulness of a G environment are the integrals of the G force, with respect to time, above 1, 4, and 7 G, and below 0 G. In this study, the G-time integrals above 1 G averaged 1745 G seconds (G-s). Dividing the value of this integral by the 27.9-min maneuvering time and adding 1 G, one arrives at an average G level during maneuvering of 2.04 G. The G-time integral above 4 G represents exposure to G stress above a relaxed person's level of tolerance to rapid-onset ( $\geq 1$  G/s) G stress (3); so the time spent above 4 G involves some degree of active resistance to the G forces, either begun voluntarily as a protective maneuver or provoked by the squeezing effect of the anti-G suit. In the present study, an average sortie accumulated 85.1 G-s above 4 G. When one divides this value by the 156.8-s average time spent above 4 G and adds 4 G, one obtains 4.54 G, the average G level sustained while above 4 G. No time was spent above 7 G on any sortie, which means that especially vigorous straining to prevent G-induced visual loss or loss of consciousness probably was not necessary. The G-time integral below 0 G averaged 1.1 G-s, with the commander contributing 86% of this integral.

There has been considerable interest recently in the rate of onset of G stress in operational high-performance aircraft, as we have come to appreciate that "snapping" abruptly to high G levels is much more likely to result in symptoms of G intolerance in flight than is a gradual transition to the high-G state (7). This is because neither the pilot's compensatory cardiovascular reflexes (4) nor his anti-G suit/valve system (1) can respond fast enough to give full protection at high G-onset rates, yet he may not have time to develop an effective straining maneuver before the peak G stress is upon him. In the present study, G-onset rates sustained long enough to result in a 2-G change of G level were recorded as high as 10 G/s. On the average, each sortie contained 31 G onsets of 4 G/s or greater meeting the 2-G change criterion; of these, 13 were at 6 G/s or greater, and 6 were at 8 G/s or greater. We expected to find that A-10 pilots subject themselves to a large number of such rapid-

onset G stresses because high-G-onset-rate jinking maneuvers are necessarily and characteristically employed by A-10 pilots to defeat enemy ground-to-air defense systems during low-level operations.

On the one sortie during which the IFPDAS module was carried in a vest worn by the pilot, a continuous record of ECG and respiratory flow was obtained. The pilot's heart rate never exceeded 120 beats/min and his minute ventilation peaked at 30 l/min. This A-10 pilot thus appeared to be physically stressed about as much as a person walking on a level surface at 5-8 km/h—certainly not a strenuous physical activity (2).

**Questionnaires:** Questionnaire A revealed the average pilot in the study to be a 33-year-old captain with 2275 h of flying time, including 261 h in the A-10. Most of the pilots participated in some sort of physical conditioning program, reporting an average of 3 h of running and 45 min of weight training each week.

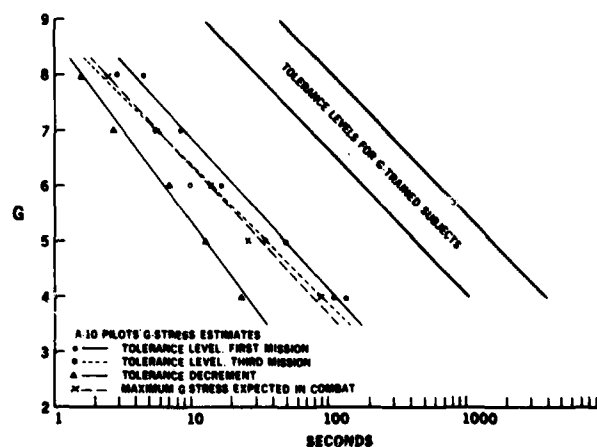


Fig. 3. Mean estimates by eight A-10 pilots of their G tolerances on the first and third missions of a given day, and the maximum G stress they expected the A-10 to generate in actual combat. Difference between mean estimated G tolerances on first and third missions is plotted as "tolerance decrement." Shaded area indicates known G tolerance of trained centrifuge riders, which is considerably greater than the pilots' estimates.

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TABLE II. G-STRESS PARAMETERS OF CENTRIFUGE-SIMULATED A-10 AND F-4 PROFILES.

Parameter	Value for A-10 profile	Value for F-4 profile
Total maneuvering time (min)	30.0	14.3
Peak +G, load	6.0	7.0
Minimum +G, load	1.0	1.0
Number of peaks:		
$\geq 7$ G	0	6
$\geq 6$ G	9	9
$\geq 5$ G	18	12
$\geq 4$ G	45	12
Time spent (s):		
above 7 G	0	0
above 6 G	0	51
above 5 G	42	87
above 4 G	196	168
G-time integral (G·s):		
above 6 G	0	39
above 4 G	140	240
above 1 G	1926	726
G-onset rate (G/s)	1.0	1.0

The pilots' estimates of their own G tolerances were obtained by means of the questionnaire, and the results are shown in Fig. 3. Although they estimated there would be a slight decrease in G tolerance after three missions in the A-10 in 1 d, the pilots felt that their tolerance, even at the end of the third mission, would be equal to or greater than the maximum G stress they would expect to experience in combat. Perhaps it is more significant that the A-10 pilots were unaware that their actual G tolerance, or at least their potential tolerance, is considerably higher than their estimates. This is evident from our experience with G-trained centrifuge subjects (8), a number of whom tolerated +9 G, for 45 s—con-

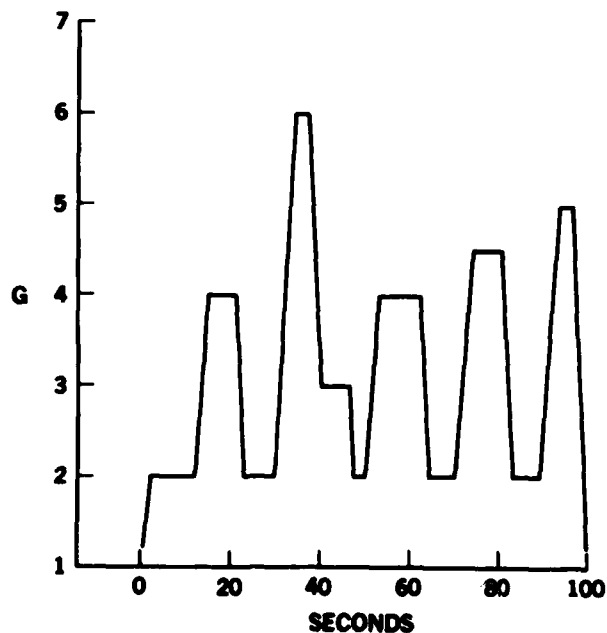


Fig. 4. Maneuvering segment of centrifuge-simulated A-10 G-stress profile. This 100-s segment was interspersed nine times among nine 1-G rest periods also lasting 100 s. The complete 30-min profile was comprised as follows: R (rest), M (maneuver), R, M, R, M, M, R, M, M, R, R, M, M, M, R, R.

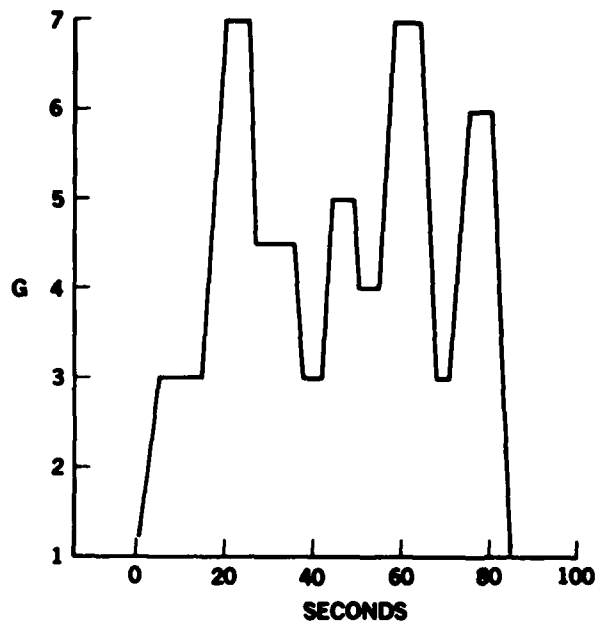


Fig. 5. Maneuvering segment of centrifuge-simulated F-4 G-stress profile used for comparison with A-10 profile. Three of these 85-s segments were separated by two 5-min rests at 1 G (total exposure time: 14 min, 15 s).

side.ably more than the A-10 pilots' mean tolerance estimates of 8 G for 4.5 s and 5 G for 49 s.

One of the questions on Questionnaire A inquired about the performance of the anti-G suit/valve system in the A-10 during maneuvering. Two of the eight pilots felt the anti-G system did not give adequate protection at operational G levels, and three indicated that suit pressure was not provided fast enough during abrupt maneuvers. There were, however, a number of spontaneous comments to the effect that G stress was not a major problem in the A-10. More of a problem, they felt, was the information-processing load associated with low-level, high-speed operations, which did create significant mental stress.

By their responses to the post-mission questionnaire (Questionnaire B), the pilots demonstrated remarkably accurate perception and recall of the inflight G loads, as the profiles they drew to exemplify the G loading during the most stressful portions of their missions agreed quite well with the IFPDAS records in terms of peak G experienced, duration of G plateaus, etc. One of the questions in Questionnaire B was, "Did you have to strain to maintain vision during high-G portions of this mission?" The pilots were given response choices of "All of the time," "Most of the time," "Some of the time," and "Not at all." Somewhat unexpectedly, the modal response was "Not at all," and the mean response was halfway between "Some of the time" and "Not at all." Another of the questions was, "Did G stress threaten to compromise your mission in any way?" The pilots responded with a unanimous "No." In fact, the comments that were offered stated emphatically that the pilots can pull more G than the A-10 can generate.

On the other hand, the pilots' responses on the subjective effort and fatigue scales did indicate that the missions were at least moderately demanding. The mean

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TABLE III. NUMERICAL RESULTS OF CENTRIFUGE SIMULATION OF 1-10 AND F-4 G STRESS (MEANS  $\pm$  S.E.M.).

Parameter	A-10	F-4	p*
Subjective fatigue score	8.4 $\pm$ 0.7	9.0 $\pm$ 1.0	NS
Peripheral light loss (%)	43.8 $\pm$ 11.5	61.3 $\pm$ 8.3	<0.02
Central light loss (%)	6.3 $\pm$ 5.0	13.1 $\pm$ 7.1	NS
Maximum heart rate (beats/min)	150.1 $\pm$ 8.7	165.6 $\pm$ 5.0	<0.01

\*probability of so great a difference (2-tailed paired t-test)

numerical estimate of physical effort exerted on the missions was 4.0 on a scale of 0 (minimum) to 6 (maximum), and the mean estimate of physical fatigue was 3.8 on the same scale. The pilots' mean estimates of mental effort and mental fatigue were a bit higher: 4.4 and 4.3, respectively, again on scales of 0–6. Five out of 18 responses indicated that cumulative fatigue, either physical or mental, was a problem during a mission. When asked to what extent G stress contributed to the fatigue, those pilots providing the five positive responses indicated that G stress was by no means entirely responsible for the fatigue. Nevertheless, most of the pilots indicated in their written comments that two or three such missions as they flew in the JAWS II exercises would be the most they could accomplish in one day without becoming fatigued to the point that flying safety would be compromised.

**Interviews:** In the interviews, the A-10 pilots reaffirmed their statements that G stress per se is not a major problem in operational A-10 flying. They also reiterated their observations of the constant vigilance necessitated by the low-level, high-speed flying, and pointed out that the tremendous information-processing load generated by the combination of offensive and defensive maneuvering requirements, ground and obstacle avoidance, navigation, communication, and weapon systems monitoring created significant mental stress. In addition, there were several comments reporting an excessive tiredness, which characteristically occurred in the late afternoon after a mid-day JAWS mission. Some pilots were of the opinion that this symptom of fatigue was a direct result of task saturation and the resulting mental stress.

**Centrifuge study:** To appreciate more fully the magnitude and character of the G stress experienced by the A-10 pilots during the JAWS II exercises, we exposed eight experienced centrifuge subjects to a 30-min simulated A-10 G-stress profile on the USAFSAM human centrifuge. This profile was obtained by matching certain parameters of the centrifuge profile (Table II) to those of the G stress recorded in the A-10 (Table I). Nine

100-s simulated aerial combat maneuvering (SACM) segments with 6-G peaks, interspersed variably among nine 100-s 1-G rest periods, comprised the simulated A-10 G-stress profile (Fig. 4). So that a comparison of the A-10 G stress could be made with a more familiar form of G stress, each subject was also exposed to three 85-s F-4 SACM segments with 7-G peaks, separated by 5-min 1-G rest periods (Fig. 5, Table II). This profile simulates a typical, hard, air-to-air training mission and is based on inflight recordings of G loads during maneuvering in the F-4E. To avoid an order effect in the comparison, half the subjects were exposed first to the F-4 profile, then to the A-10 profile, while the other half were exposed in the reverse order. Exposures to the two forms of G stress were separated by at least 24 h. The subjects were required to drive the centrifuge by moving a control stick to track a programmed cross on a video screen located directly in front of the subject in the centrifuge cockpit; by tracking the cross, the subjects generated the required A-10 or F-4 G profile themselves, just as a pilot would G-load himself by tracking a maneuvering target. ECG and heart rate were continuously recorded during each centrifuge run. Immediately after each run, the subjects reported the percent loss of brilliance of a red light upon which they fixated during the run (central light loss) and the percent loss of brilliance of two green lights situated 25° to the right and left of the red light (peripheral light loss). Approximately 3 min after the centrifuge stopped, each subject filled out a subjective fatigue checkcard which provided a fatigue score ranging from 0 (exhausted) to 14 (refreshed). After a subject completed both exposures, he was asked, "Which profile was more difficult?" and "On which profile did you have more visual loss?" The response, "A-10," "F-4," or "Neither," was recorded for each question.

Tables III and IV convey the results of the centrifuge study. Although the 30-min A-10 profile resulted in slightly more subjective fatigue than did the 14-min F-4 profile, the difference was not significant. The mean reported peripheral light loss of 61% during the F-4 profile was significantly greater than the 44% loss during the A-10 profile. This is not surprising: the F-4 profile peaks at 7 G, whereas the A-10 profile peaks at 6 G, and the primary determinant of G-induced visual loss is G level. Even though the mean reported central light loss during the F-4 profile was twice that reported for the A-10 profile (13% vs. 6%), this difference was not statistically significant. The means of the maximum heart rates observed during exposures to the A-10 and F-4 G-stress profiles were significantly different at the 0.01 level. This result is indicative of the greater amount of physical effort required to tolerate the higher peak G loads of the F-4 profile; i.e. the anti-G straining maneuver was necessarily more vigorous during exposure to the F-4 G-stress profile than during exposure to the A-10 profile. Analysis of cardiac dysrhythmias occurring during exposures to the two profiles provided little useful information. Of the 193 dysrhythmic beats observed in the study, 165 occurred in one subject; the remaining 28 were more or less randomly distributed among the other subjects. No apparent predominance of dysrhythmic beats occurred in either profile.

TABLE IV. CENTRIFUGE SUBJECTS' ASSESSMENTS OF A-10 AND F-4 G STRESS.

Question	Number of subjects answering		
	"A-10"	"F-4"	"Neither"
"Which profile was more difficult?"	4	4	0
"On which profile did you have more visual loss?"	0	7	1

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The subjects' assessments of the relative difficulty of the two G-stress profiles (Table IV) resulted in half answering that the A-10 profile was more demanding and half saying the F-4 profile was more demanding. Those considering the A-10 profile more difficult complained about the long duration of the A-10 G exposure, while those considering the F-4 profile more difficult were challenged by the higher G levels of that profile. When asked which profile was associated with greater visual loss, the subjects made a clearer distinction: seven noticed more visual loss on the F-4 profile, and one said the two profiles generated equal visual loss, but none claimed to have had more visual loss on the A-10 profile. This result is consistent with the numerical results on peripheral and central light loss reported above, and is attributable to the simple fact that, other factors being equal, +7-G stress decreases eye-level blood pressure more than does +6-G stress.

The centrifuge study thus indicates that the G loads characteristic of A-10 missions are no more stressful physiologically than those of F-4 missions, and are in all probability less stressful. This is evidenced by the fact that the subjects had significantly lower heart rates and less visual loss during exposure to the A-10 profile than during the F-4 profile.

### DISCUSSION

The data presented on A-10 G stress can be compared with the 1971 data of Leverett *et al.* (5), who recorded G loading, ECG, and respiration in F-4E pilots during the ACM phase of the Instructor Pilot Course, USAF Fighter Weapons School, Nellis Air Force Base, NV. The records of 35 ACM engagements from nine F-4E sorties revealed a maximum of +8.7 G, with seven of the 35 engagements exceeding +6.5 G. Although a maximum of only +6.7 G was recorded in the nine A-10 sorties of the JAWS II exercises, four of those nine sorties exceeded +6.5 G. The F-4E pilots spent an average of 115 s per engagement, and an average of 14.6 s above +5.0 G, per engagement. Considering that 3.89 engagements (35/9) were accomplished per sortie, an average sortie in the Nellis AFB F-4Es involved 56.8 s above +5.0 G. This is roughly twice the per-sortie mean of 29.7 s above +5.0 G, in the A-10s involved in JAWS II. Not represented by this comparison, however, is that the F-4E pilots spent much more time above 5.0 G on each excursion above that level. While the mean effective maneuvering time for the A-10s was 27.9 min on each sortie, that for the F-4Es was only 7.5 min, which implies that the G exposure was more concentrated in the F-4E engagements. This is exemplified by Leverett's observation that the maximum time spent above 5.0 G in one particular F-4E engagement was 44 s. In contrast, the maximum time spent above 5.0 G in the A-10 study was 50 s for one sortie, but 36 separate greater-than-5.0-G peaks, spread more or less evenly over 28 min of maneuvering, were required to accumulate that 50 s.

Certainly, these figures confirm what one can conclude by watching the A-10 and F-4 in action. The characteristic acceleration pattern of the A-10 is one of many peaks of relatively brief, moderate-level G force, dis-

persed throughout a long-sustained attack; whereas that of the F-4 is a few periods of relatively sustained, moderate-level G force, with occasional high-G peaks, applied during several short but very intense engagements. The results of this difference in terms of physiologic stress is fairly clear. The relative absence of G-induced visual symptoms in the A-10 pilots, and the significantly less visual loss in centrifuge subjects exposed to the A-10 G profile as opposed to the F-4 profile, result from one simple fact: neither the amplitude nor duration of any single G peak experienced in the A-10 is remarkably great, and the product of these two parameters could only rarely be expected to approach Stoll's classic G-amplitude/duration blackout-tolerance curve (9). The same certainly cannot be said of G stress in the F-4. On the other hand, the repetitive nature of the G stress generated in the A-10 probably does result in at least some fatigue-related attenuation of pilots' capacities, as evidenced by several pilots' responses on the post-mission questionnaires and by the responses of those centrifuge subjects who felt the sheer duration of the A-10 profile made it more difficult than the shorter F-4 profile.

### CONCLUSION

The G-stress environment of the A-10 aircraft flying its intended mission in a realistic exercise has been sampled and described. The necessity for defensive jinking maneuvers during combat necessitates numerous short exposures to G levels in the 4-7 G range, but acute symptoms of G intolerance in A-10 pilots are nearly nonexistent. The length of an A-10 mission, with the resulting repetitiveness of the G exposure, may contribute to pilot fatigue. Of far more importance to the pilots than G stress, however, is the problem of task saturation.

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